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# PATENT SPECIFICATION

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## (54) GRINDING MACHINE

(71) We, CINCINNATI MILACRON-HEALD CORP., a Corporation organised and existing under the laws of the State of Massachusetts of New Bond Street, Worcester, Massachusetts, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed to be particularly described in and by the following statement:—

The present invention relates to grinding machines. In the operation of grinding machines, one of the problems that often arises is that, as the diameter of the abrasive wheel becomes smaller, it tends to cut faster. While fast stock removal is desirable in some parts of a grinding cycle, it is often undesirable particularly at the finish. Although this is true whenever grinding a surface of revolution it is particularly true in the case of internal grinding where the diameter of the wheel is very close in size to the diameter of the bore; this means that a change in the diameter of the wheel due to wear and to the dressing operations brings about a much greater disparity in relative diameters of wheel and bore than would be true in the case of external grinding where a very large grinding wheel is used. More rapid stock removal results in a number of effects, the most important of which is that the finish of the surface deteriorates. Other factors that come about because of this faster cutting rate (due to the smaller size of the wheel) relate to the amount of taper in the bore due to deflection of the spindles and to the size of the bore. Attempts to reduce the feed rate in accordance with reduction of the diameter of the abrasive wheel have been made in the past, but the apparatus for doing this is an automatic grinding machine has been complicated and expensive and easily changed so that adjustment is lost. These and other difficulties experienced with the prior art devices have been reduced in a novel manner by the present invention.

In general, the invention consists of a grinding machine for generating a surface of revolution

on a work piece, having a base, a work-head table mounted on the base having a support for rotating the workpiece, and a wheel-head table mounted on the base having a rotatable spindle on which an abrasive wheel is mounted. Feed means is provided for bringing about relative motion between the work-head table and the wheelhead table transversely of the axis of the surface of revolution, the feed means including an actuator for producing a rough grind with controlled-force conditions and a motor for producing a finish grind with controlled-rate conditions. Control means is provided for adjusting the rate of feed during the said finish grind in accordance with the size of the abrasive wheel.

More specifically, the said motor is an electrical stepping motor. Preferably the feed means is operative on the wheelhead table to bring about the said relative movement, a compensation slide lies between the wheelhead table and the base, and the said motor is operative to move the compensation slide by an incremental amount every time a dressing operation takes place, the control means including a potentiometer having two relatively movable parts one of which is fixed to the base and the other of which is connected to the compensation slide to partake of the same incremental amount of movement. The potentiometer may produce an electrical signal indicative of the compensation slide position and of wheel size, and this electrical signal is fed into a pulser to control the rate of pulses fed to the motor during the finish grind.

The invention, however, may be better understood by reference to one of its structural forms, as illustrated by the accompanying drawings, in which:

Figure 1 is a plan, somewhat schematic, view of a grinding machine embodying the principles of the present invention.

Figure 2 is a diagram showing the various integrated circuits used in controlling the grinding machine; and

Figure 3 is an electrical schematic diagram of a portion of the apparatus.

Referring first to Figure 1, which best shows the general features of the grinding machine, the grinding machine, indicated generally by the reference numeral 10, is of the general type shown and described in the U.S. Patent No. 3,403,480, and the U.S. Patent No. 3,503,158. The grinding machine 10 consists of a base 11 on which is mounted a workhead 12 carried on a workhead table 13, which is capable of sliding motion on ways 14 extending parallel to the axis of a surface of revolution 15 of a workpiece 16 which is to be finished. Also mounted on the workhead table 13 is a dressing apparatus 17 having a diamond. Extending through the workhead 12 for engagement with the workpiece bore (surface of revolution 15) is a pneumatic gauge 18 of the type shown and described in the U.S. Patent No. 2,771,714. This gauge is suitably connected to pressure switches (not shown) capable of indicating when the size of the bore has reached an intermediate size at which the finish grind is to be terminated, and indicating when the size of the bore has reached the final size.

Also mounted on the base 11 is a wheelhead table 25 which is slidable on ways 23 and 24 to move transversely of the axis of the surface of revolution 15. Both the table 13 and the table 25 are movable under the impetus of hydraulic linear actuators to produce their respective motions. Lying on the base 11 and slidable over its surface is a compensation slide 26. Extending from the wheelhead table 25 is a finger 27 aligned to engage a forwardly-facing feed stop 28 which is located on the forward face of the compensation slide. The finger 27 and the feed stop 28 are also arranged as an electrical switch for placing the pneumatic gauge 18 in operative condition on occasion, as is well known.

The wheelhead table 25 is also provided with a downwardly-extending finger 29 which is in position to engage a rearwardly-directed dress stop 31 formed on the compensation slide 26. There is a considerably greater distance between this finger 27 and the finger 29 than there is between the feed stop 28 and the dress stop 31, so that the table 25 is capable of a wide range of operative movement between these two portions, such motion being brought about by a suitable hydraulic cylinder 32. This cylinder is arranged with the usual servo valves and so on to produce very quick action in moving the wheel head table 25 from a first position where the finger 27 engages the feed stop 28 to the second position at which the finger 29 engages the dress stop 31. Mounted on the table 25 is a wheelhead 33 carrying a rotatable spindle 34, the outer end of which carries an abrasive wheel 35. The cylinder 32 is provided with hydraulic fluid at a carefully regulated pressure, so that it is possible to predetermine

the force producible by the cylinder and use that force for engagement of the abrasive wheel 35 with the workpiece 16 according to the well-known "controlled-force" grinding principle. The back end of the compensation slide 26 is threadedly engaged with a ball screw 36 which is driven through suitable gearing by a stepping motor 37. The stepping motor, the screw 36, and the compensation slide 26 operate to give a readily-selected accurate compensation at the time of dress, in accordance with the teachings set forth in the U.S. Patent No. 3,403,480 mentioned above. The finger 27 is engaged with the front of the cross-slide or wheelhead table 25 through a screw 38 to provide a certain degree of adjustment. This adjustment takes place by a ratchet 39 mounted on the front of the screw 38 and operated in opposite direction by pawls 40 and 41 slidable back and forth by means of cylinders 42 and 43. A handwheel 44 operates through a rod 45 to permit manual operation of the screw 36 to provide for minor adjustments of the compensation slide 26.

A main control 46 feeds a pattern of electrical pulses through a cable 47 to the main stepping motor 37 and, at the same time, through the cable 48 to a control panel 50. At one side of the panel is located a visual slide position indicator 51 which shows the cross-slide position at any given time. Also mounted on the panel is a New Wheel lamp 53, a Coarse-Compensation device 54 and corresponding lamp 55, a Cycle Start Device 56 and a corresponding lamp 57, and a worn wheel device 58 and its lamp 59, as well as a New Wheel Device 60 associated with the lamp 53. The panel 50 is constructed in accordance with the U.S. Patent No. 720,912.

Mounted on the base 11 beside the compensation slide 26 is a potentiometer 61 having a movable arm 62 which is connected to a nut 63 engaged by the ball screw 36. The nut is moved back and forth when the screw rotates. In other words, the movement of the arm 62 is in synchronization with the compensation slide 26.

Referring now to Fig. 2, it can be seen that the stepping motor 37 receives its driving pulses through the cable 47 from a driver 64, forming part of the main control 46. The stepping motor, of course, serves indirectly to move the arm 62 of the potentiometer 61 which is connected by a cable 65 to the main control 46 and, particularly, to a rate modulator 66. The rate modulator is connected by a line 67 to a pulser 68. The pulser output passes through a line 69 to a pulse-to-step converter 71. This output, in turn, passes through a line 72 to the driver 64 for the stepping motor. The output of the pulser also passes through a down-counter 73 through a line 74. Similarly, the output of the pulser also passes through a line 130

75 to an up/down counter 76. An input interface 77 passes a signal through a line 78 to a count selector logic 79; it is also connected through a line 81 to a feed logic 82. The output of the feed logic goes to the count selector logic 79 by way of a line 83. Another output of the feed logic 82 is connected to the pulser 68 by means of a line 84 and also to the pulser by way of a line 85 and rate switches 86. The up/down counter 76 has an output which is connected by a line 87 to a memory 88 which, in turn, is connected by a line 89 to the input side of the feed logic 82. The up/down counter 76 has an output connected through a line 91 to a readout 92, and also has an output connected through a line 93 to a logic output 94, the logic output also receiving signals from position-setting switches 95 by a line 96. The logic output 94 is also connected by a line 97 to the conventional machine controls. The input interface 77 is similarly connected by a line 98 to the conventional machine controls in the well-known manner.

The count selector logic 79 receives a signal from the down counter 73 through a line 99. It has an output signal which passes through a line 101 to the pulse-to-step converter 71. Another output passes through a line 102 to the input side of the pulser 68. Another output of the count selector logic 79 passes through a line 103 to count setting switches 104 whose output passes through a line 105 to the down counter 73. Finally, the feed logic 82 is connected by a line 106 to the up/down counter 76.

In Fig. 3 it can be seen that the potentiometer 61 actually contains three resistors 107, 108, and 109 connected from a common ground to a 24-volt supply line. The central resistor 108 is the actual potentiometer resistor contacted by the arm 62, which is connected by the line 65 to the rate modulator 66 which, in turn, is connected by the line 67 to the pulser 71. Circuitry in the rate modulator 66 makes use of two operational amplifiers 111 and 112 with suitable connections and resistors in the usual way to amplify the signal from the potentiometer 61 and pass it to the pulser.

The operation of the machine will now be readily understood in view of the above description. The grinding cycle takes place in the usual way, i.e. a new wheel is placed on the spindle 34, the raw wheel is dressed down to a standard size, and the regulator grinding cycles are started on a succession of workpieces. The cycles continue with occasional dressing until the wheel diameter is reduced to the worn wheel size, at which time a new wheel is mounted on the spindle. As the negative and positive pulses are introduced to the main stepping motor 37 to move the wheelhead table 25 back and forth during the successive grinding cycles, this is indicated

on the control panel 50. Furthermore, the arm 62 is moving in synchronisation with the compensation slide 26, so that the voltage appearing on the arm and transmitted to the rate modulator 66 is indicative at all times with the position of the compensation slide 26. As the successive workpieces are ground and the machine passes from the new wheel position to the worn wheel position, the compensation slide moves rearwardly across the base 11 in the usual way. When the cycle starts out with a roughing grind under controlled-force conditions under the impetus of the cylinder 32 and finishes with the controlled-rate conditions under the control of the motor 37, the signal emanating from the potentiometer 61 decreases or becomes lower and lower as the wheel becomes smaller. This means that the voltage passing through the rate modulator 66 and, eventually, passing through the line 67 to the pulser 68 becomes smaller and smaller. The pulser passes pulses to the main motor 67 at a slower rate, thus reducing the rate at which the table 25 is moved transversely during the finish portion of the grinding cycle to a lower quantity. This compensates for the fact that, as the wheel becomes worn, its diameter is smaller, its radius of curvature is smaller, and, therefore, it cuts at a faster rate. Thus, by reducing the rate of feed as the wheel becomes smaller, it is possible to maintain the finish on the work-piece at a predetermined quality while, at the same time, maintaining the size and the taper equally at a preset value. It should be noted that all of the circuits shown in Fig. 2 are integrated circuits and as such are readily replaceable for repair of the machine. They are also relatively indestructible and more or less standard in manufacture and so are relatively inexpensive. At the same time, because the rate of feed is maintained at a constant value, there is a tendency to maintain the deflection of the spindle at a constant value, which tends to keep the force between the abrasive wheel and the workpiece at a constant value, all of which tends to maintain the finish of the surface of revolution at a fixed amount as the wheel wears from the new wheel to the worn wheel.

#### WHAT WE CLAIM IS:—

1. A grinding machine for generating a surface of revolution on a workpiece, comprising
  - (a) a base,
  - (b) a workhead table mounted on the base and having a support for rotating the workpiece,
  - (c) a wheelhead table mounted on the base and having a rotatable spindle carrying an abrasive wheel,
  - (d) feed means for bringing about relative motion between the workhead table

- and the wheel head table transversely of the axis of the surface of revolution, the feed means including an actuator for producing a rough grind with controlled-force conditions and a motor for producing a finish grind with controlled-rate conditions, and
- 5 (e) control means for adjusting the rate of feed during the said finish grind in accordance with the size of the abrasive wheel.
- 10 2. A grinding machine as claimed in Claim 1, wherein the said motor is an electrical stepping motor.
- 15 3. A grinding machine as claimed in Claim 1 or 2, wherein the feed means is operative in the wheel head table to bring about the said relative movement, wherein a compensation slide lies between the wheelhead table and the base, wherein the said motor is operative to move the compensation slide by an incremental amount every time a dressing operation takes place, and wherein the control means includes a potentiometer having two
- 20 relatively movable parts one of which is fixed to the base and the other of which is connected to the compensation slide to partake of the same incremental amount of movement.
4. A grinding machine as claimed in Claim 3, wherein the motor is connected to the compensating slide by a ball screw, and wherein the rotation of the screw produces a corresponding movement of a contactor in the potentiometer.
5. A grinding machine as claimed in Claim 4, wherein the potentiometer produces an electrical signal indicative of the compensation slide position and of wheel size, and wherein this electrical signal is fed into a pulser to control the rate of pulses fed to the motor during the finish grind.
6. A grinding machine substantially as described herein and with reference to the accompanying drawings.
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## COMPLETE SPECIFICATION

2 SHEETS

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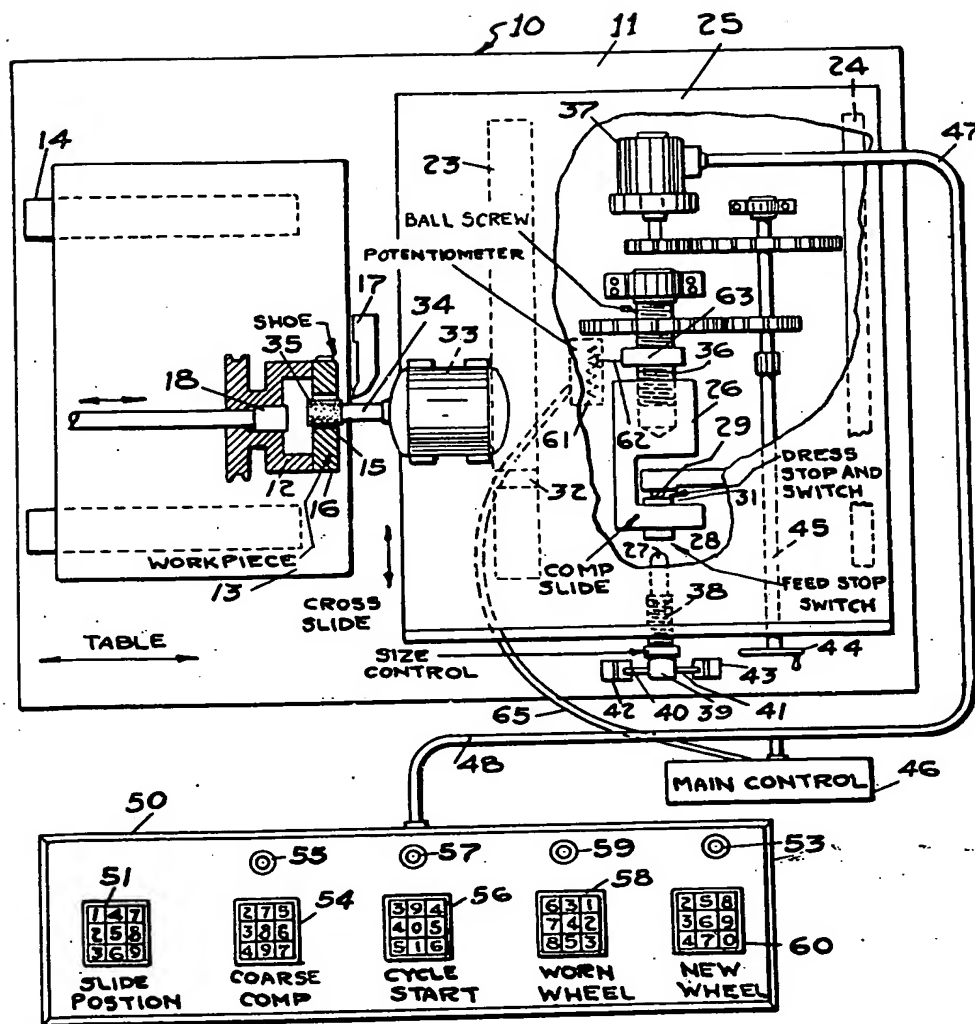


FIG. 1.





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